Philippine Archipelago Experiment: High-Resolution Towed Body Surveys of Submesoscale Variability

Craig M. Lee, Michael C. Gregg, Joseph P. Martin and Jack B. Miller
Applied Physics Laboratory, University of Washington
1013 NE 40th St.
Seattle, WA 98105-6698
phone: (206) 685-7656 fax: (206) 543-6785 email: craig@apl.washington.edu
phone: (206) 543-1353 fax: (206) 543-6785 email: gregg@apl.washington.edu
phone: (206) 897-1623 fax: (206) 543-6785 email: martin@apl.washington.edu
phone: (206) 543-9959 fax: (206) 543-6785 email: miller@apl.washington.edu

Grant Number: N00014-06-1-0687
http://opd.apl.washington.edu/~craig

LONG-TERM GOALS

This study contributes to long-term efforts toward understanding:

- Dynamics of coastal circulation.
- Strongly forced mesoscale and submesoscale dynamics.
- Processes that communicate atmospheric forcing to the ocean interior.

OBJECTIVES

The proposed observational program focuses on understanding:

- Means and direction by which information gets routed through the archipelago. Is the flow of information primarily westward? Are the signals important in establishing the interior flow, or is the latter primarily driven by wind and other local forcing?
- Processes governing flow partition in multiply-connected domains, including investigations of flow separations, internal waves, instabilities and sidewall eddy generation.
- The dominant dynamical balances that characterize the flow at different locations and scales.
- Response to (relatively) small-scale wind shear created by orographic effects on monsoon winds.

APPROACH

Directed by remotely sensed sea surface temperature, wind speed and ocean color images, repeated surveys employing towed profiling vehicles characterized the temporal evolution and three-dimensional structure of selected features.

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **30 SEP 2008**	2. REPORT TYPE **Annual**	3. DATES COVERED **00-00-2008 to 00-00-2008**

4. TITLE AND SUBTITLE **Philippine Archipelago Experiment: High-Resolution Towed Body Surveys Of Submesoscale Variability**	5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **University of Washington,Applied Physics Laboratory,1013 NE 40th St.,Seattle,WA,98105-6698**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

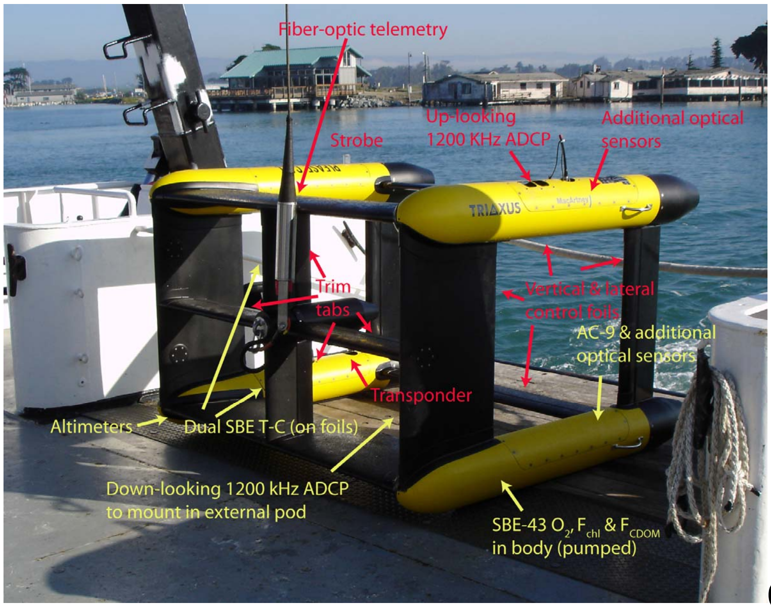
13. SUPPLEMENTARY NOTES
code 1 only

14. ABSTRACT
This study contributes to long-term efforts toward understanding ? Dynamics of coastal circulation. ? Strongly forced mesoscale and submesoscale dynamics. ? Processes that communicate atmospheric forcing to the ocean interior.

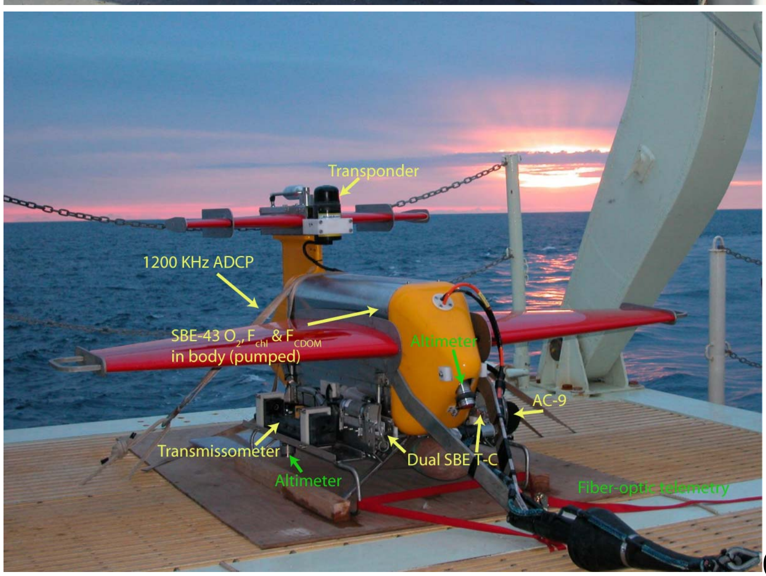
15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**9**	

Three towed profiling vehicles (Triaxus, TriSoarus and SWIMS3) address the challenges posed by the



(a)



(b)

Figure 1. (a) Triaxus and (b) TriSoarus towed profilers. Triaxus can exert lateral control and operates over a wide range of tow speeds. TriSoarus is a hybrid SeaSoar with electric wing actuation and over-sized flight surfaces. Both carry SBE911+ CTD systems and an advanced fiber-optic MUX that eases sensor integration. An electro-optical tow cable provides high-bandwidth telemetry. The two vehicles share winch, tow cable, electronics, terminations, control and data acquisition systems. Vehicles can be exchanged rapidly, with minimal reconfiguration, as part of routine operations.

rapidly-evolving, three-dimensional nature of submesoscale features within Lombok Strait. The vehicles offer complementary sampling capabilities that allow rapid, broad-reaching surveys,

measurements near the surface and bottom boundaries, provide lateral resolutions of O(100–1000 m) and support a dense array of physical and optical sensors. Triaxus offers rapid tow speeds that allow broad, synoptic coverage while SWIMS3 provides extremely steep profile angles to maximize lateral resolution in smaller survey regions.

The Triaxus ‘E model’ (Fig. 1a) is a new-generation towed profiler that has recently passed its sea trials. Triaxus profiles from the surface to 350 m (or deeper, depending on sea state) at tow speeds of 2 – 10 knots and can profile offset to the side, outside of the towing vessel’s wake (providing improved

surface layer characterization). Large foils control pitch and yaw, while smaller trim tabs stabilize the vehicle against roll. Vertical speed remains nearly constant (typically chosen as 1 m/s) throughout the profile. We also operate a hybrid SeaSoar (TriSoarus, Fig. 1b) that has been modified to improve flight performance when operating on unfaired tow cables. Dual single-mode fibers provide high-bandwidth telemetry to support a broad range of sensors. Both vehicles accommodate extensive payloads including dual Seabird C-T, 1200 kHz ADCPs, SBE43 dissolved oxygen, Wetlabs transmissometer, chlorophyll and CDOM fluorometers, additional optical sensors added by Jones and Boss, attitude package, dual Tritech altimeters and an acoustic transponder.

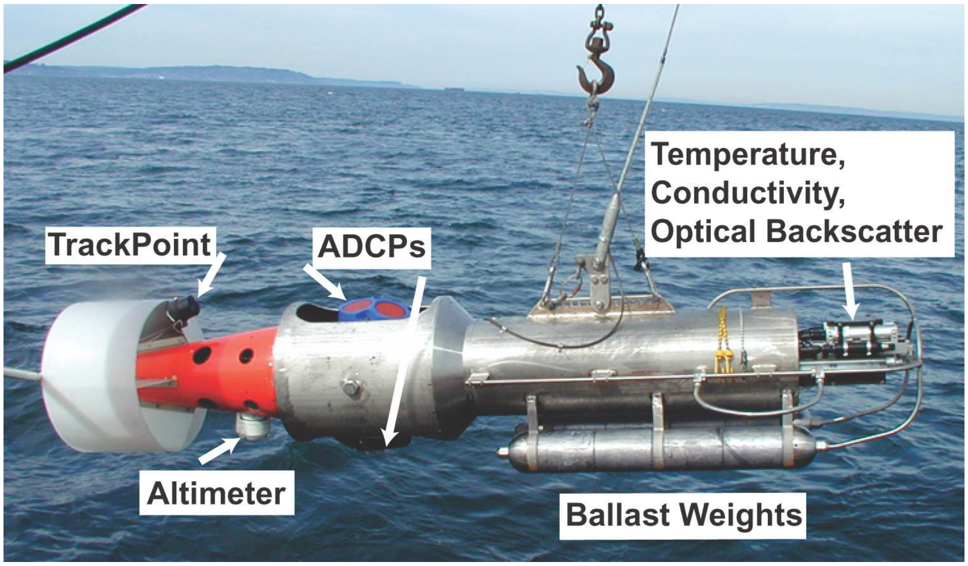


Figure 2. SWIMS2. The SBE 911+ CTD samples duplicate T and C sensors, SBE dissolved oxygen, SeaPoint fluoresence and OBS-3 particulates, all housed in small cases mounted on the instrument's nose. The upward and downward ADCPs are 300~kHz Workhorse Monitors with beams inclined 20^o from vertical. The TrackPoint transducer allows acoustic position tracking. Internal tilt and roll sensors monitor body attitude. The two lead skids protect the instruments when the body hits bottom.

SWIMS3 is a towed, profiling body being developed under NSF support from the successful SWIMS2 (Fig. 2) design. SWIMS2 saw extensive use in Puget Sound, Knight Inlet, the North Pacific and the Black Sea before being lost in rough operating conditions due to cable failure. Weighing 850 lbs in air, SWIMS3 vehicles will be winched up and down while being towed at speeds of 2 – 6 knots. Vertical speeds exceed 1 m/s, allowing SWIMS3 to achieve extremely steep profiles and exceptional lateral resolution. Maximum depth depends on cable length and tow speed. Payload includes dual Seabird C-T, SBE43 dissolved oxygen, D & A Instruments OBS-3 optical backscatter, SeaPoint chlorophyll fluorometer, up- and down-looking 300 kHz ADCPs (with 20° beams), attitude package, Tritech altimeter and Trackpoint transducer (for vehicle tracking).

WORK COMPLETED

The February 2007 Melville cruise focused on characterizing:

- Response to small-scale wind forcing created by monsoon winds passing through the steep topography of Mindoro.
- Response to a small-scale wind jet produced by a mountain gap.
- Flow around Apo Reef.
- Response to wind shear off southern Mindoro
- Watermass properties and circulation within the ‘mixing bowl’ formed by the constrictions leading in and out of the junction between Mindoro and Panay.

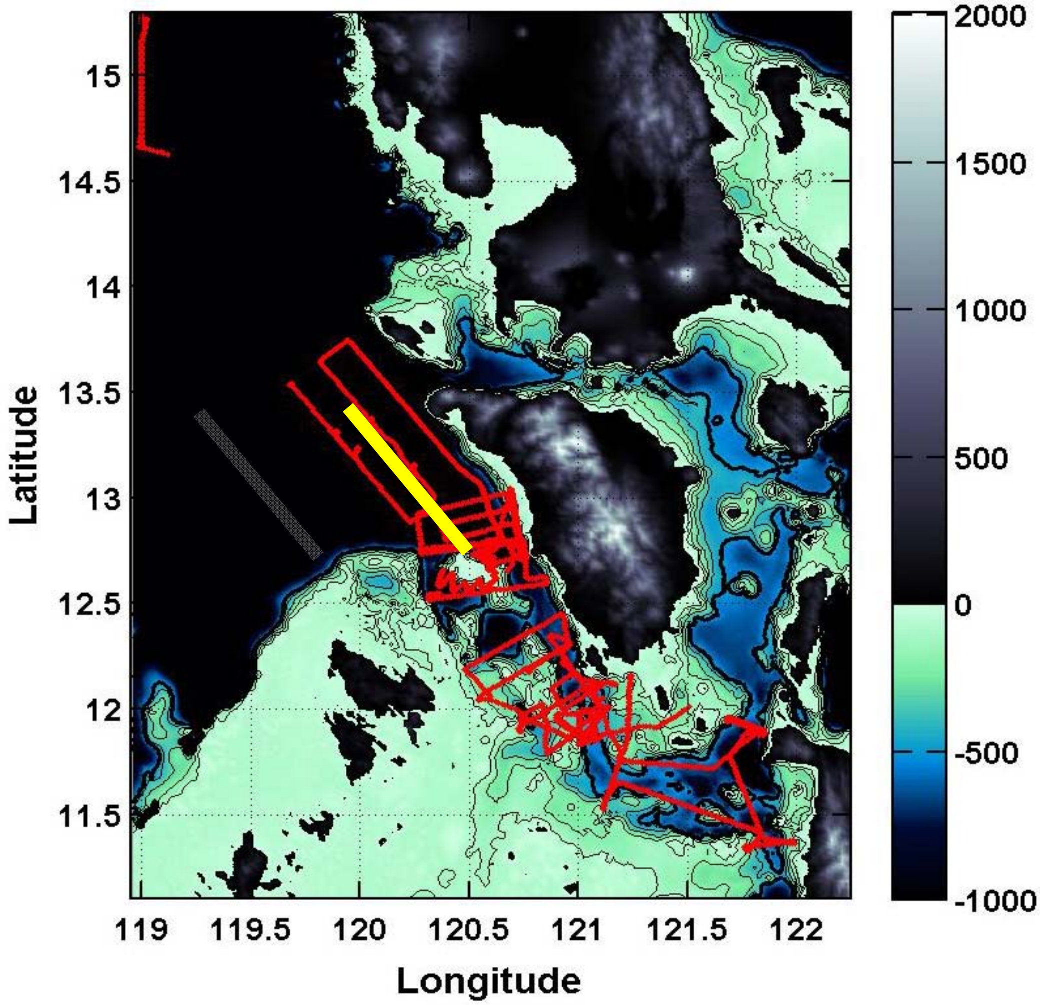


Figure 3. Surveys conducted during the 7 – 27 February 2008 R/V Melville cruise. Red lines mark towed profiler survey tracks. The yellow line marks the section plotted in Fig. 5.

Although remote sensing identified strong windstress curl accompanied by a pair of eddies east of Luzon/Mindoro, a medical emergency forced Melville to return to Manila, canceling plans investigate the features described in the recent Pullen at el. (2008) manuscript. When sampling resumed, efforts focused on response to intense wind shear off the northern end of Mindoro (Fig. 3, grid pattern

centered at ~13° 15' N, Fig. 4 and Fig. 5). Subsequent surveys sampled response to the strong, narrow wind jet produced by a mountain gap on Mindoro Island (Fig. 4, ~13° N) and investigated flow separation and mixing around Apo Reef (Fig. 6). The remainder of the cruise was devoted to sampling the complex channels and sills off the southern end of Mindoro (also a region of forced by strong windstress curl) and to characterizing the entrances, exits and along-path watermass evolution of the 'mixing bowl' at the junction between Mindoro and Panay. Surveys of the southern Mindoro and of the triple junction 'mixing bowl', where water passing around Panay Island rejoins Mindoro Strait, offer excellent opportunities to investigate how the Archipelago's complex geometry impacts mixing and circulation, though the data await detailed analysis.

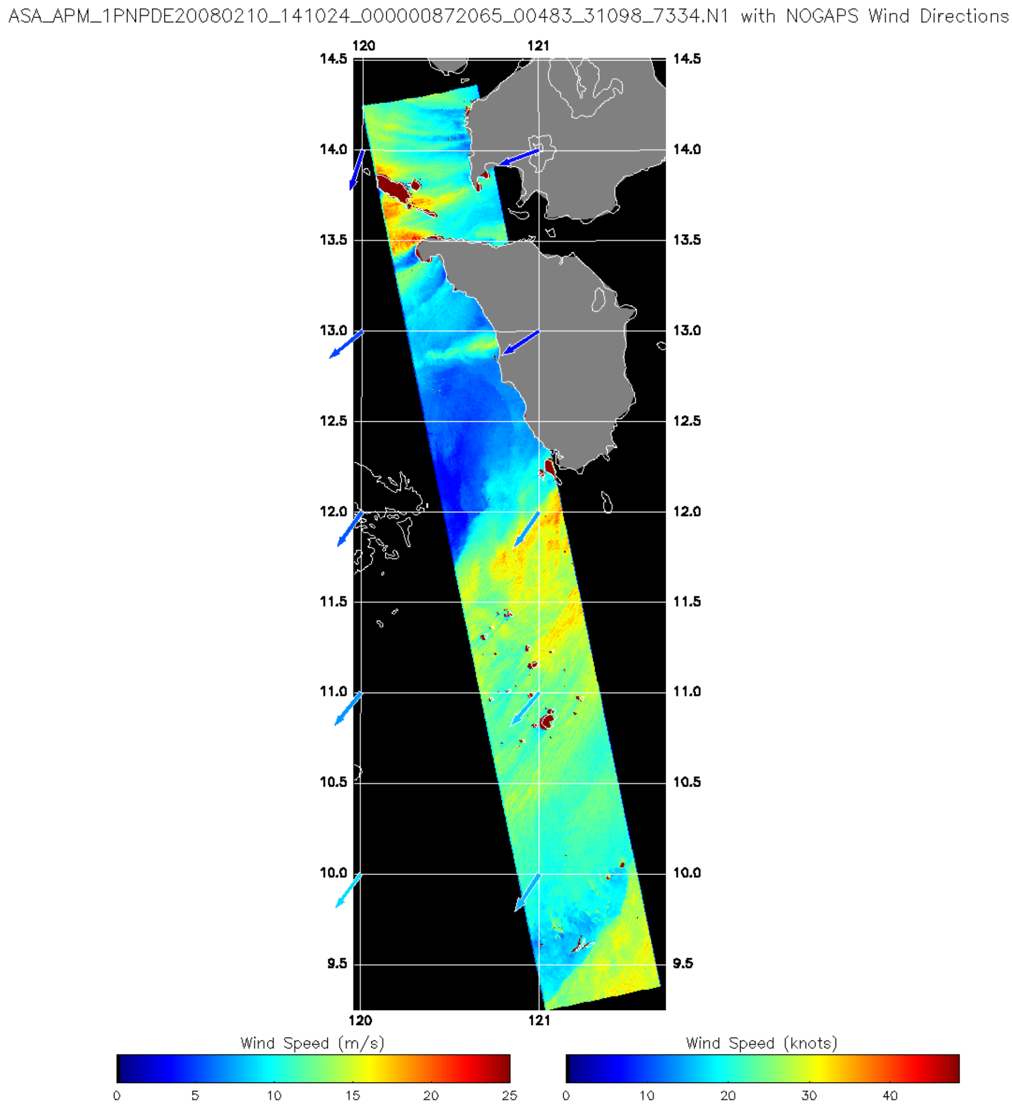


Figure 4. SAR image off Mindoro Island, with wind speed inferred from surface roughness. Speeds peak at ~40 knots, with strong lateral shears, off the northern tip of Mindoro. A gap in the high mountain ridge that runs along the center of Mindoro produces a weaker wind jet that extends offshore at ~13° N.

The towed profiling effort benefitted greatly from interactions with other elements of the Philippine Archipelago program. Remotely sensed measurements, including SAR-derived wind speed (Jackson, GOA), ocean color and sea surface temperature (Arnone and colleagues, NRLSSC) and model results (Pullen, NRLMRY) informed and guided day-to-day sampling strategies. Following the approach developed during previous collaborations, detailed optical measurements (Jones, USC; Boss, UM; Arnone, NRLSSC) were collected in close coordination with the physical data. Towed profiling surveys provided information for developing highly targeted sampling plans for a specialized optical profiling package. Survey data are available for use in PhilEx numerical efforts, where we anticipate utility for model evaluation efforts.

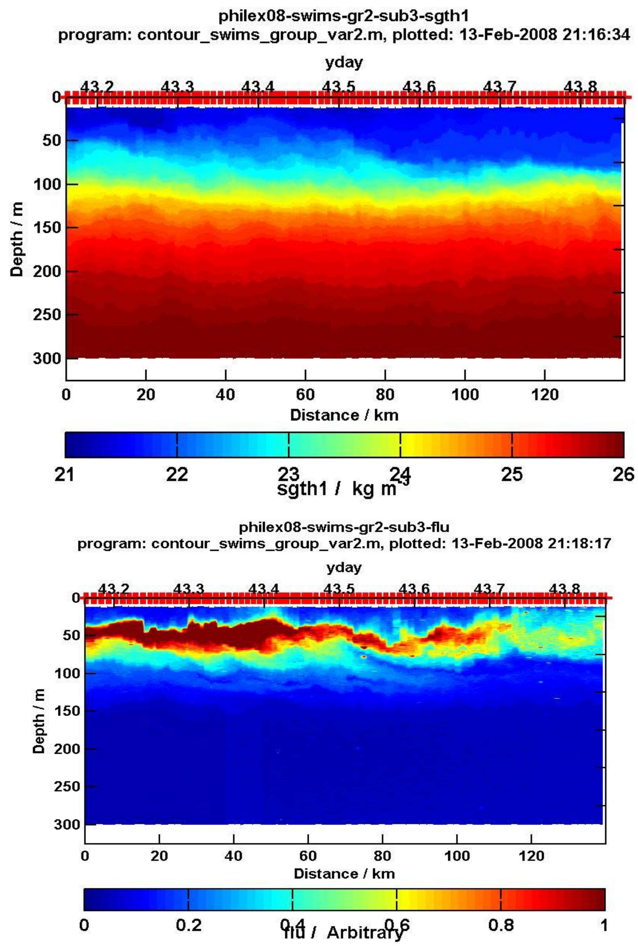


Figure 5. Potential density (upper) and chlorophyll concentration (shown as unscaled fluorometer output) along the nearshore line off NW Mindoro (thick yellow line in Fig. 2, plotted south-to-north). At ~80 km along the track, near the transition from weak to strong wind stress, the mixed layer deepened and active turbulence entrained chlorophyll from the mixed layer base into the surface layer.

RESULTS

Sections occupied off the northwest end of Mindoro Island characterized the upper ocean response to the strong wind shear (Fig. 4). Signatures were weak along the two western legs, but wind effects were

dramatic along the inshore leg, with the mixed layer deepening over an interval of a few kilometers (Fig. 5). Rapid vertical diffusion of chlorophyll concentration indicated entrainment of material that farther north was restricted to the stably stratified mixed layer base. More extensive measurements sampled the ocean beneath the narrow wind jet farther south on Mindoro Island. This region featured sharp horizontal wind speed contrasts. During the nearshore runs transitions into and out of the jet were marked by very rapid wind speed changes (weak to 20+ knots and back again) that could be readily felt on deck. Because the wind jet remained steady through our sampling period, the surveys should provide synoptic, three-dimensional maps of the velocity and water property perturbations produced by this sharp wind forcing.

The Apo Reef surveys provide another example of the small-scale dynamics that represent the towed profiling effort's focus. Here, measurements investigated the potential for the reef, and similar

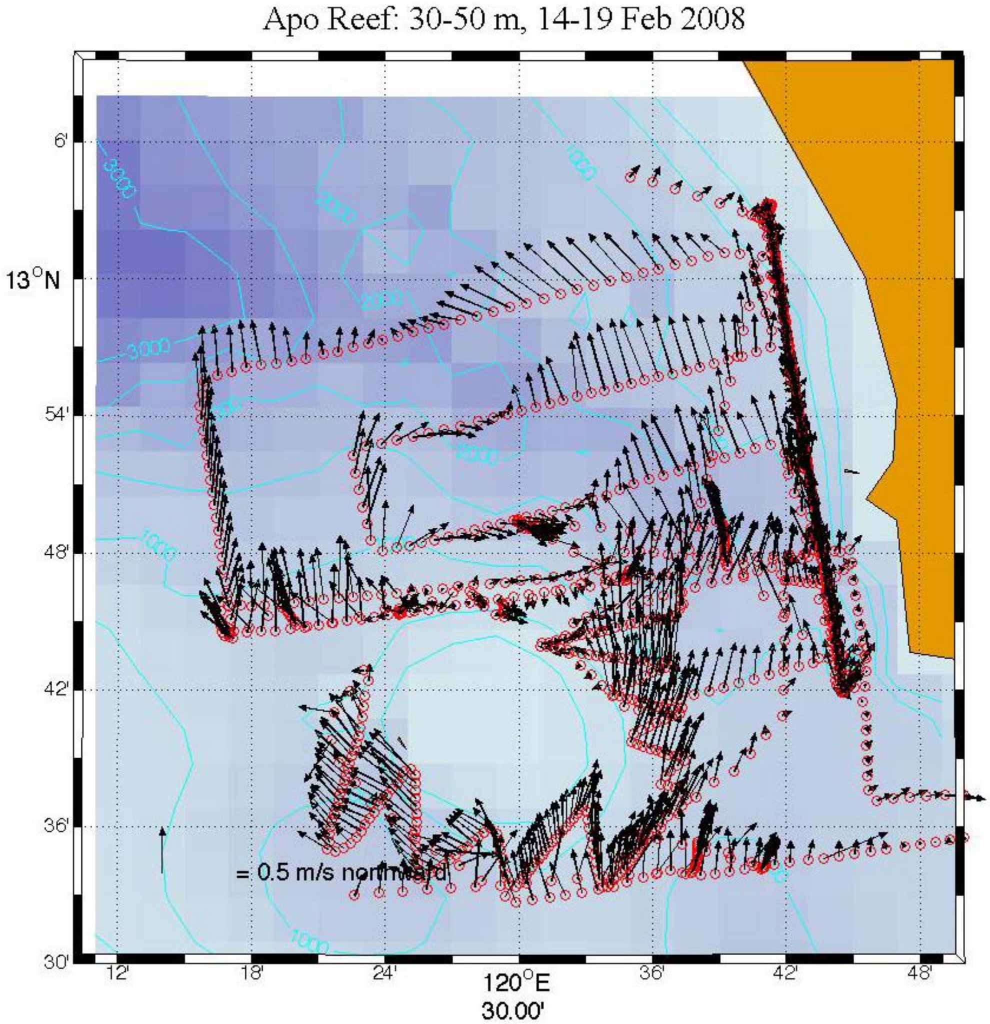


Figure 6. Apo Reef surveys. Red dots mark profile locations with accompanying velocity vectors (averaged over 30 – 50 m). The reef is outlined by the closed isobath contour (light blue) in the lower center. Northward flow appears to separate from both sides of the reef, though the eastern separation is most prominent.

features, to function as stirring rods, enhancing mixing for strong flows through Philippine Archipelago Straits. Sawtooth surveys attempted to map flow separations as surface-intensified

northward currents passed around the reef (Fig. 6). Since this is an important fishing site for Mindoro islanders, science operations aroused considerable interest and many questions from fisherman, handled gracefully by the Philippine coast guard officer and his naval counterpart, onboard as observers. Uncertain knowledge of the local bathymetry (we relied on the most recent navigation charts, circa 1930) complicated close approaches to the reef, making it difficult to fully resolve the feature's impact on circulation and mixing. Despite this limitation, surveys captured flow separation on both sides of the reef (though separation is clearest to the east) along with eddy-like structures in the lee (Fig. 6). These surveys also reveal upper-layer northward flow along both sides of Apo Reef, contrary to the southward currents depicted in some of the numerical simulations and in moored measurements (Alford and Girton, personal communication). Other surveys (e.g those taken during the summertime Exploratory cruise) also show northward currents in the upper layer.

IMPACT/APPLICATION

None.

TRANSITIONS

None.

RELATED PROJECTS

Bio-Optical Response and Coupling with Physical Processes within the Philippine Archipelago, B. Jones (USC) and Emmanuel Boss (UM).

Satellite remote sensing of Ocean Color and SST as indicators of the flow through the Philippine Archipelago, R. Arnone, S. Lander and B. Casey (NRLSSC).

Regional Stratification and Shear of the various inflow and outflow streams of the Strait, A. Gordon (LDEO) and A. Ffield (ESR).

Regional circulation and sub-mesoscale dynamics of the Philippines archipelago, C. Ohlmann (UCSB).

Throughflow in the Philippine Archipelago, J. Sprintall (SIO).

Internal Tide Radiation from a Strait, J. Girton and M. Alford (APL-UW).

High frequency radio remote sensing of the mesoscale flow, P. Flament (UH).

Investigation of Remote Sensing Imagery for the Philippine Waters, C. Jackson (GOA).

REFERENCES

Pullen, J., J. D. Doyle, P. May, C. Chavanne, P. Flament and R. A. Arnone, 2008. Eddy Shedding in the South China Sea Triggered by Monsoon Surges. *Submitted to Geophysical Research letters*.

PUBLICATIONS

None.